NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 325

FLIGHT TESTS ON U. S. S. "LOS ANGELES" PART II—STRESS AND STRENGTH DETERMINATION

By C. P. BURGESS

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.^{2} $=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 $=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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EXECUTIVE COMMITTEE

REPORT No. 325

FLIGHT TESTS ON U. S. S. "LOS ANGELES"

PART II: STRESS AND STRENGTH DETERMINATION

By C. P. Burgess

SUMMARY

The tests described in this report furnished data on the actual aerodynamic forces, and the resulting stresses and bending moments in the hull of the U. S. S. "Los Angeles" during as severe still-air maneuvers as the airship would normally be subjected to, and in straight flight during as rough air as is likely to occur in service, short of squall or storm conditions. The maximum stresses were found to be within the limits provided for in accepted practice in airship design. Normal flight in rough air was shown to produce forces and stresses about twice as great as the most severe still-air maneuvers. No light was thrown upon the forces which might occur in extreme or exceptional conditions, such as the storm which destroyed the "Shenandoah."

The transverse aerodynamic forces on the hull proper were found to be small and irregular. Owing to the necessity of conserving helium, it was impossible to fly the airship in a condition of large excess of buoyancy or weight in order to determine the air pressure distribution at a fixed angle of pitch. However, there is every reason to believe that in that condition the forces on the actual airship are as close to the wind-tunnel results as can be determined by present type of pressure measuring apparatus.

It is considered that the most important data obtained are the coefficients of tail-surface forces and hull-bending moments. These are tabulated in this report.

INTRODUCTION

The only known experimental determinations of the stresses in the girders of rigid airships in actual flight, previously to the investigations described in this report, were carried out upon the U. S. S. *Shenandoah* in 1923 and 1924, and upon the U. S. S. *Los Angeles* in 1925. The previous experiments were carried out by the Bureau of Aeronautics, using the Bureau of Standards type of electric telemeter strain gage. At the time of the *Shenandoah* experiments suitable recording apparatus had not yet been developed for these instruments, and the investigations were limited by the inability of the observer to watch the simultaneous movements of more than a very few milliameter needles. The experiments on the *Los Angeles* in 1925 were carried out with the strain gages and recording apparatus described in the report; but the program of experiments was short, owing to a projected long-distance flight of the airship; and there was no coordination with external air pressure determinations.

The series of flight tests forming the subject of this report were undertaken with the U. S. S. *Los Angeles* in April and May, 1926, after careful planning to avoid the shortcomings of previous experimental work. The assistance of the National Advisory Committee for Aeronautics was requested, and the pressure distribution investigation was placed in their hands. Part I of this report deals with the work of the National Advisory Committee for Aeronautics. In this, the second and concluding part of the report, the stress determinations are described and coordinated with the other data of the experiments.

It was realized that the roughest air which the ship might encounter in service was not likely to be experienced in these tests, but it was hoped to overcome this difficulty by correlating

the pressures and stresses with the angular accelerations shown by a recording turn indicator, which could be carried regularly as part of the airship's service equipment for recording the angular accelerations occurring in the worst conditions in continued service. Unfortunately, the turn indicator proved to be unsatisfactory, and that part of the experiment was unsuccessful.

APPARATUS AND INSTALLATION

The strain gages were developed by the Bureau of Standards for the Bureau of Aeronautics, Navy Department. The principle of operation of these gages is that the electrical resistance of a stack of carbon piles or disks mounted under pressure in a frame varies rapidly with small changes of the length of the frame. In the stacks used in these gages, the electrical resistance varies about 46 per cent for a change of length of only 0.00217 inch. With a single stack, the change of resistance is not linear with the change of length, but if two stacks are incorporated in a strain gage designed to increase the length of one stack and decrease the length of the other stack equally, they may be arranged in a Wheatstone bridge circuit in which the deflection of a milliammeter or oscillograph will be directly proportional to the change of strain. Such an arrangement is shown diagrammatically in Figure 1.

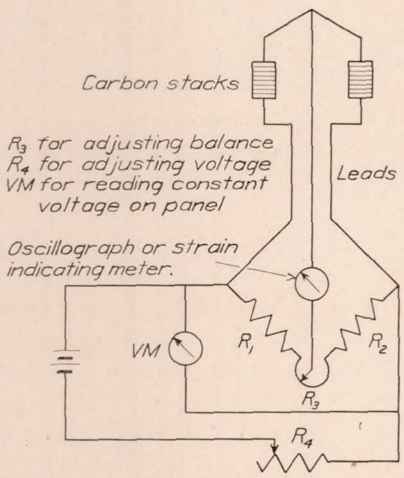


FIGURE 1.—Diagram of circuit of strain gage

The two branches of the bridge circuit consist of the carbon stacks and leads in series on the one hand and the resistances R_1, R_2, and R_3 on the other hand. R_1 and R_2 are fixed resistances, and R_3 a slide wire resistance by means of which a fine degree of balance of the bridge is obtainable. The bridging instruments are a milliammeter in the visible indicating element, and a mirror galvanometer reflecting a beam of light in the photographic recorder; they are connected between the midpoint of the carbon stacks and the movable contact on R_3. The bridge is energized from the battery shown at the left of the diagram; the current is kept at the proper constant value by means of the variable resistance R_4.

The gage which carries the carbon stacks and is clamped to the member to be investigated is shown in Figure 2. The gage length is approximately 7.8 inches; the length of the leads to the indicating and recording apparatus is 100 feet.

Figure 3 shows the indicating instrument. The left-hand milliammeter and the series rheostat are for controlling the constant bridge current. The right-hand milliammeter is for reading the relative flow of current through the stacks, and hence their changes of length and resistance. It may be arranged to read one milliampere per 0.001-inch or per 0.0005-inch change of strain. By means of the keys across the middle of the instrument and the transfer switch in the center front, 12 different gages may be cut into the circuit. The leads from the 12 gages are secured to the binding posts shown at the back. The leads at the right go to an aluminum recorder box (fig. 4), which contains 12 mirror galvanometer elements, one for each strain gage. The beams of light reflected from the galvanometers make traces on a roll of sensitized bromide paper contained in the camera (fig. 5) and driven by an electric motor.

The precision of the strain gages is not particularly good. Owing to backlash and hysteresis and a tendency of the carbon piles to a gradual change in their calibration, errors approaching 25 per cent may occur.

The strain gages were installed in three groups, each group having its own recorder. The positions of the gages are given in Tables I and II. Gages 1 to 12, recording on camera No. 3, were placed forward on the longitudinals between frames 115 to 160.

Gages 13 to 24 were strung along longitudinals 1S and 1P, which are the second rows of longitudinals up from the bottom of the airship (see Fig. 2 in Part I of this report) and on the

upper longitudinals of the keel, designated KS and KP, between frames 40 and 85. These gages recorded on camera No. 2.

Gages 25 to 35, recording on camera No. 1, gave much the most interesting and important records. They were secured to the longitudinals in the lower half of the hull, just forward of frame 70, in the region of maximum bending moments from rudder and elevator action.

FLIGHT TESTS

The program of flight tests was explained in Part I. For convenience, it is again summarized in Table III of this part of the report.

Four flights were made during the series of tests. The time, air temperature, altitude, and corrected sea-level barometer of each test run are recorded in Table IV.

DETERMINATION OF THE AERODYNAMIC BENDING MOMENTS

In the strain gage records, a vertical deflection of 1 cm in the record line corresponds to a change of strain in the girder equal to 0.001 inch in the gage length of 7.8 inches. Assuming

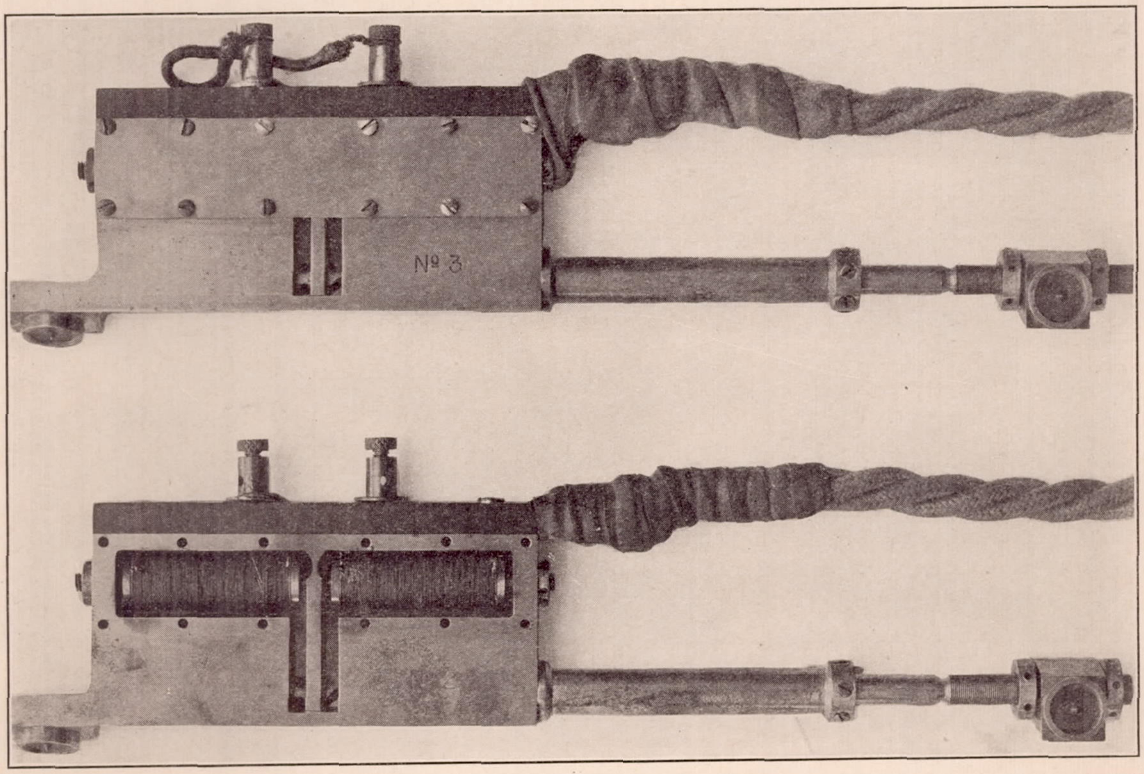


FIGURE 2.—Strain-gage elements for clamping to girders

that the modulus of elasticity of duralumin is $E = 10{,}500{,}000$ lb./sq. in., the stress in the girder per centimeter deflection of the record is equal to $10{,}500{,}000 \times 0.001/7.8 = 1{,}350$ lb./sq. in. If the section modulus of the cross section of the hull is known, and if the distribution of longitudinal stress is in accordance with the ordinary theory of bending, the bending moment in the hull at any cross section is the product of the section modulus and the maximum longitudinal fiber stress.

The maximum bending moments from forces on the tail surfaces are to be expected between frames 70 and 85. At frame 70, the strain gages were distributed nearly half way around the hull, so that the records include an approximation to the extreme fiber stress for all longitudinal planes of bending. The theoretical mean section modulus at frame 70 is 66 meters $\times$ square inches. Theory and experiments have indicated that the distribution of stress is not in direct

linear proportion to the distance of the members from the neutral axis, but more nearly resembles a parabolic relation in which the stress in the extreme fiber is only about seven-eighths as great as if the linear stress distribution of the ordinary bending theory occurred. The theoretical section modulus is therefore multiplied by $8/7$, making its effective value 75.5 m sq. in. (The combination of meters and square inches may appear curious, but it is very convenient because the even 5-meter spacing of the frames makes the meter-pound a handy unit for measuring the bending moment, and the division of the bending moment in meter-pounds by

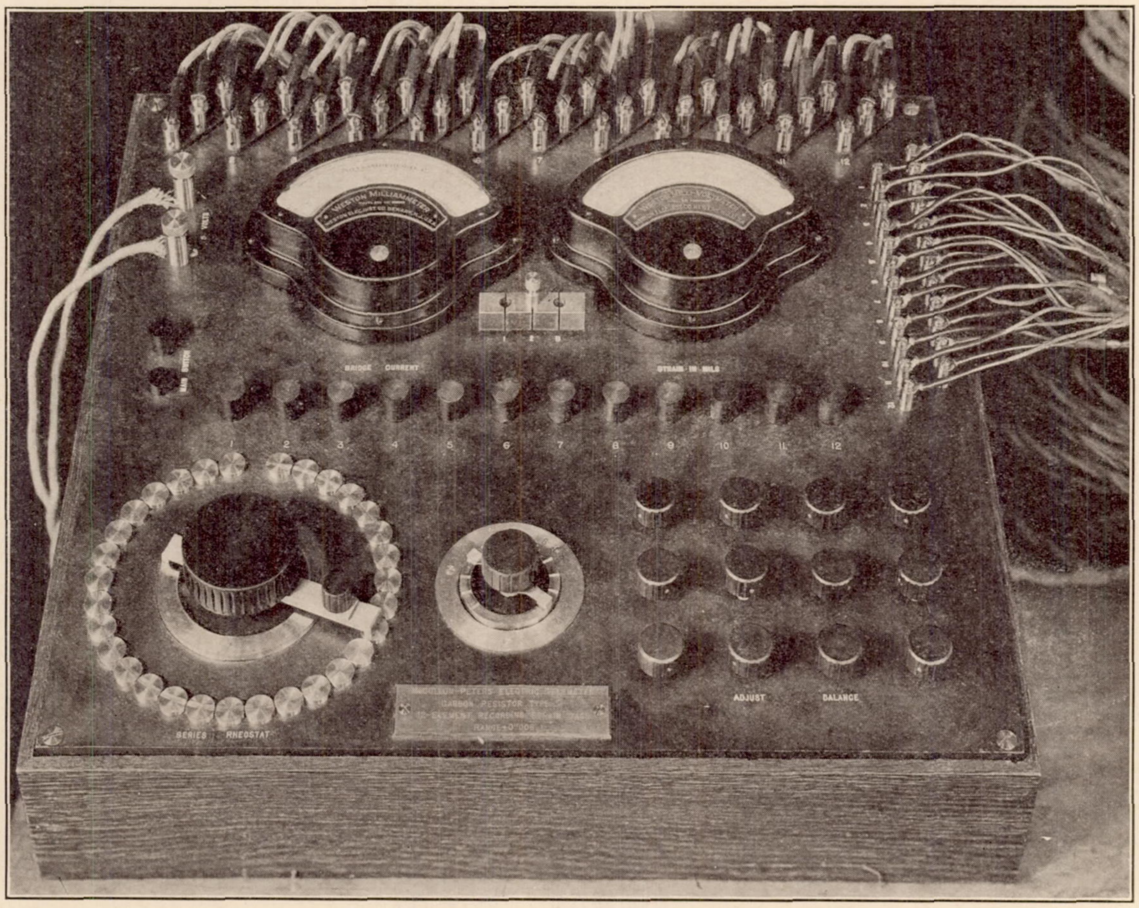


FIGURE 3.—Strain-gage indicating apparatus

the section modulus in meter-square inches gives the stress in the customary engineering units of pounds per square inch.)

Converting the deflections of the strain gage record into stress, and thence into bending moment, 1 centimeter deflection represents $1{,}350 \times 75.5 = 102{,}000$ m lb. bending moment.

The sensitized paper was moved through the camera at a mean rate of about 4.5 inches per minute. In tests in which the strain gage recorders were synchronized with the N. A. C. A. instruments, timing lines at 16 seconds intervals were thrown upon the paper by momentarily cutting off the lights.

DISCUSSION OF THE STRAIN GAGE RECORDS

Some typical strain gage records are shown in Figures 6 to 16. Since the strain gages show only changes of stresses in flight, and there are no clearly defined lines or levels of stress which may be regarded as representing either the normal static condition or straight flight in still air, the analysis of the aerodynamic bending moments is based upon the amplitude of stress, or half the total range of stress recorded during any particular maneuver or test run. It might

be thought that in a steady turn, the stresses in any one member would vary in only one direction from the normal; but, in reality, there is a reversal of stress even in maneuvers not involving a reversal of the helm. The reason for this is that when the helm is first put over, a transverse air force is created on the rudders, opposed by the inertia of the airship against angular accelera-

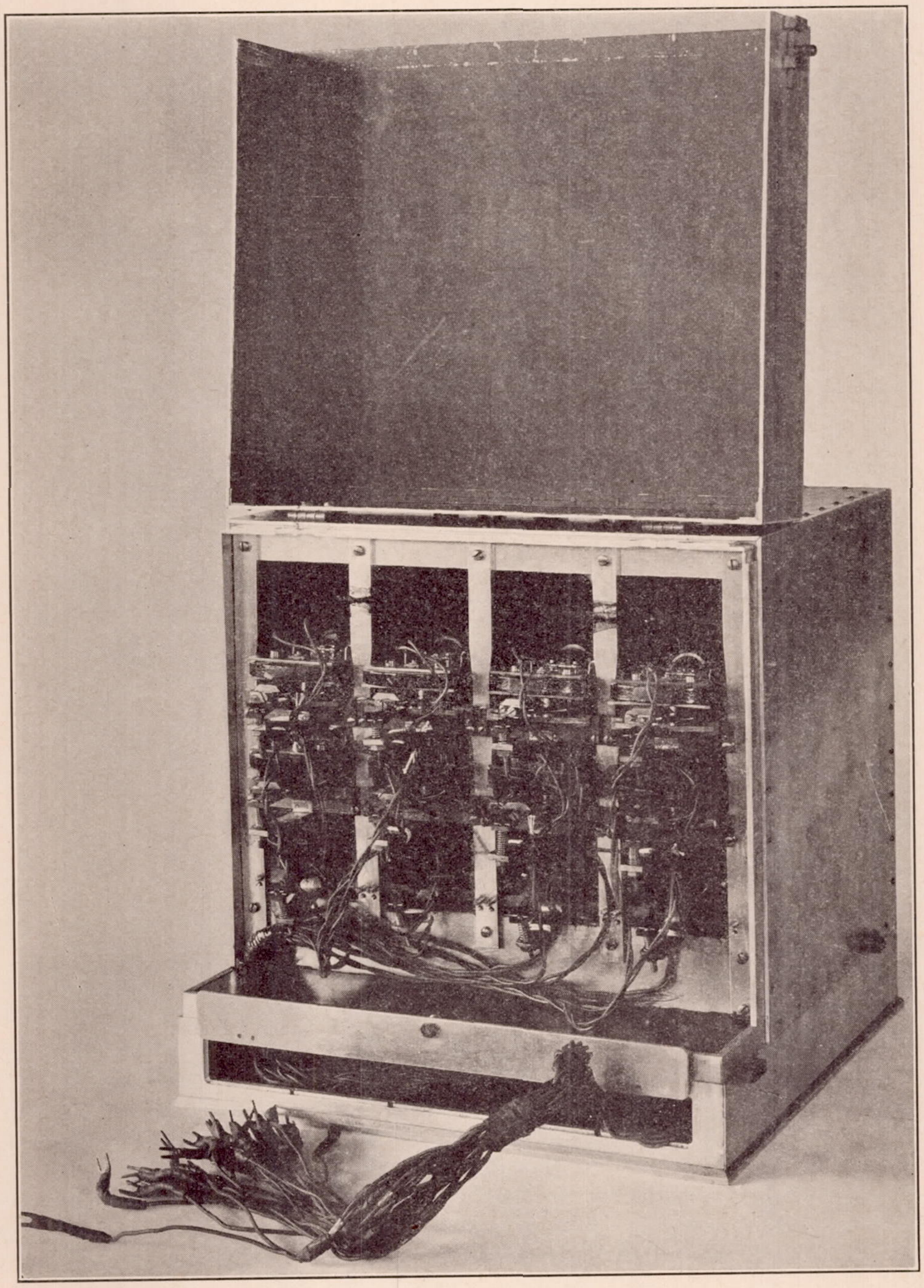


FIGURE 4.—Recording apparatus, interior seen from behind

tion. This produces a moment to bend the airship in the opposite sense to the direction of the coming turn. In other words, during the initial period of angular acceleration, the forces on the bow and stern act outwardly from the center of the turning circle. Later, when the airship has settled to the condition of steady turning without angular acceleration, the direction of the bending moment is reversed by the diminished force on the rudders and the creation of aero-

dynamic forces on the bow and fins, acting inwardly toward the center of the turning circle, opposed by the outwardly acting centrifugal forces distributed along the hull.

Gages 1 to 12 installed in the forward part of the airship, were the old original gages which had been used in the *Shenandoah* three years previously. Their records were not sufficiently satisfactory for quantitative measurements. They agreed with the air-pressure measurements in indicating that the transverse forces on the airship's forebody were small and irregular Undoubtedly much greater forces and strains would have been recorded on the forebody if

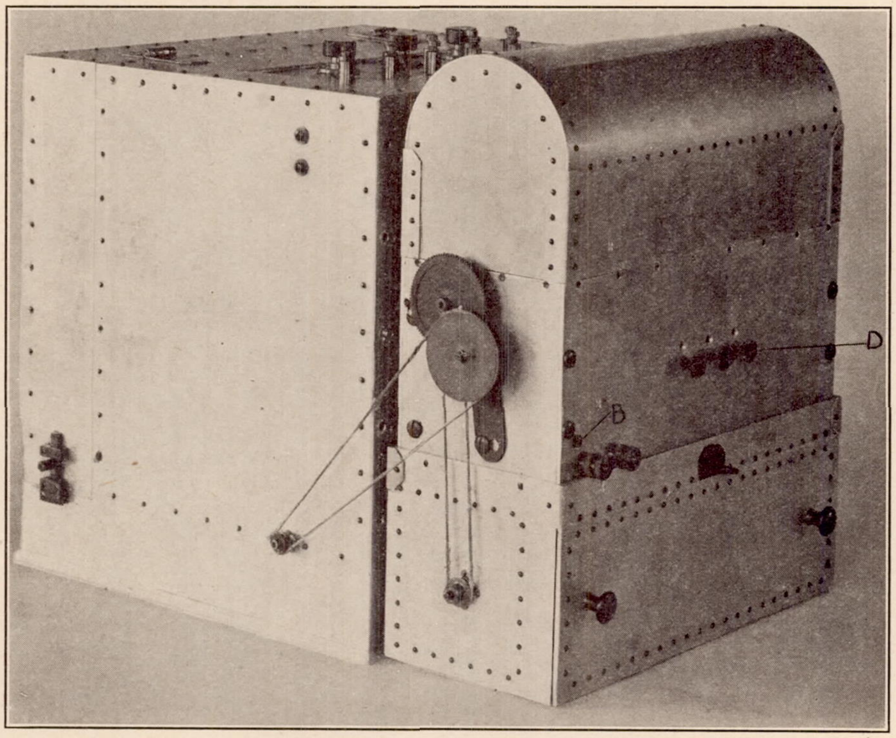


FIGURE 5.—Exterior view of recorder and camera

the airship had been flown at the angles of pitch required to offset large inequalities of weight and buoyancy.

Figures 6 to 11 and Figure 16 are typical records from the strain gages grouped on the longitudinals around frame 70, as listed in Table II.

Figure 6 is the record obtained in run No. 4B. The maneuver was a steady turn with 9.7° left rudder. The stresses were small and fluctuating, indicating that they were primarily the result of disturbances in the air rather than of bending moments imposed by the maneuver.

Figure 7 is an interesting record showing well-defined stresses varying continuously from one side of the airship to the other, as would be expected from a lateral bending moment.

Figure 8 is principally of interest in showing the reversal of stress resulting from reversal of the helm when the airship executes an S curve.

Figure 9 shows the strongly fluctuating stresses which are characteristic of the period just after leaving the mooring mast. An important feature of this record is that bending moments in the vertical plane are indicated by large stresses of the same signs and approximately equal magnitudes in the longitudinals at the top of the keel and the lower part of the hull, showing that the keel behaved as an integral part of the hull, and not as a separate beam. According to the shear theory, and some other theories of stress distribution, the top member of the keel should show stresses of opposite sign to the bottom member when the hull is subjected to vertical bending.

Figure 10 shows a rather gradual reversal of stresses during an S turn.

Figure 11 is a record of an S turn in which the stresses due to the maneuver were overlaid by fluctuating stresses resulting from disturbed air.

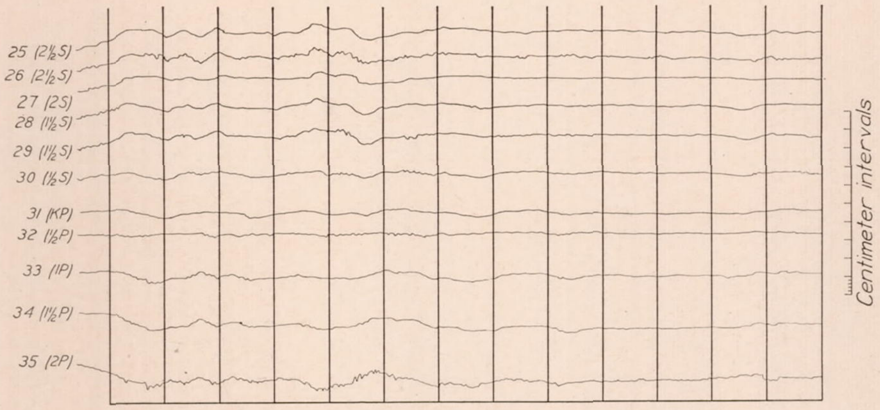


FIGURE 6.—Camera No. 1. Run No. 4

Figures 12 to 15, inclusive, are the records of the gages extended longitudinally along the bottom of the airship as recorded in Table II. Only Figure 15 of this group is of much sig-

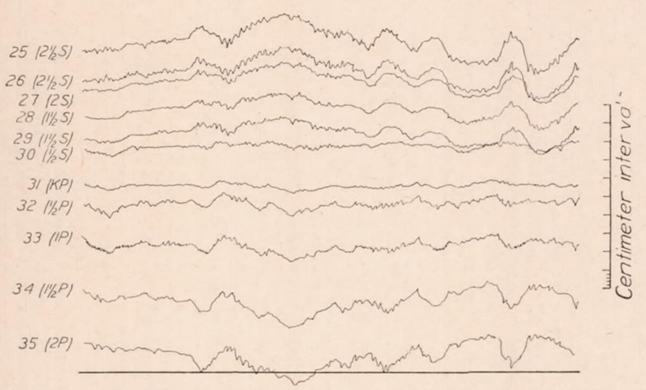


FIGURE 7.—Camera No. 1. Take-off from mast

nificance. It was taken during the critical period after leaving the mast. The fluctuations of stress are large, rapid, and irregular.

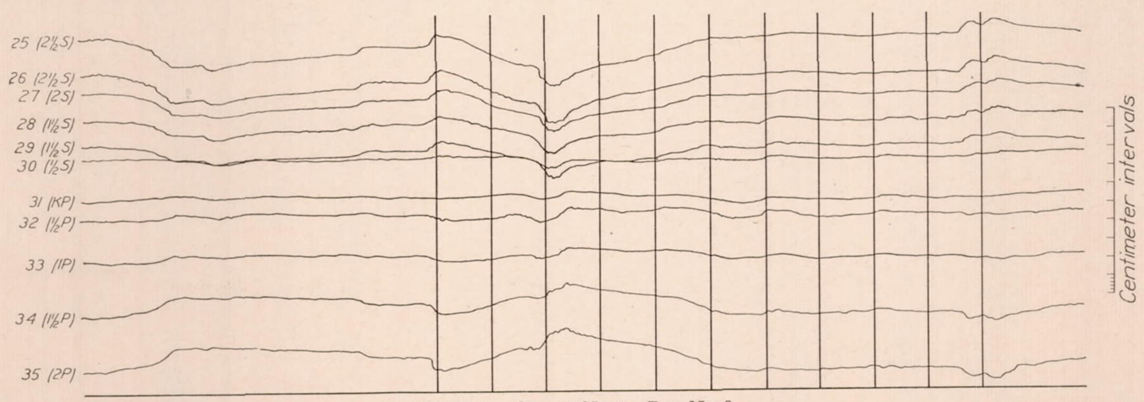


FIGURE 8.—Camera No. 1. Run No. 3

Figure 16 is typical of the large stresses during the rough air of the first day of the trials. This record was not synchronized with the N. A. C. A. normal force measurements, but it is

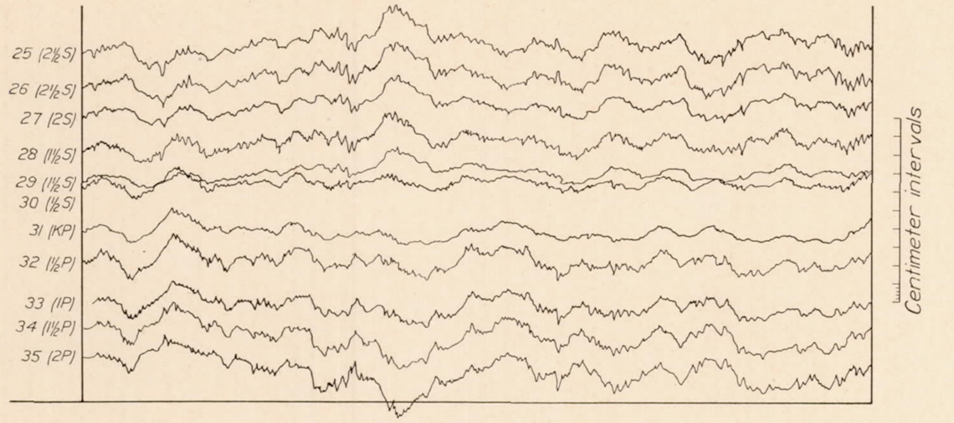


FIGURE 9.—Camera No. 1. Take-off from mast

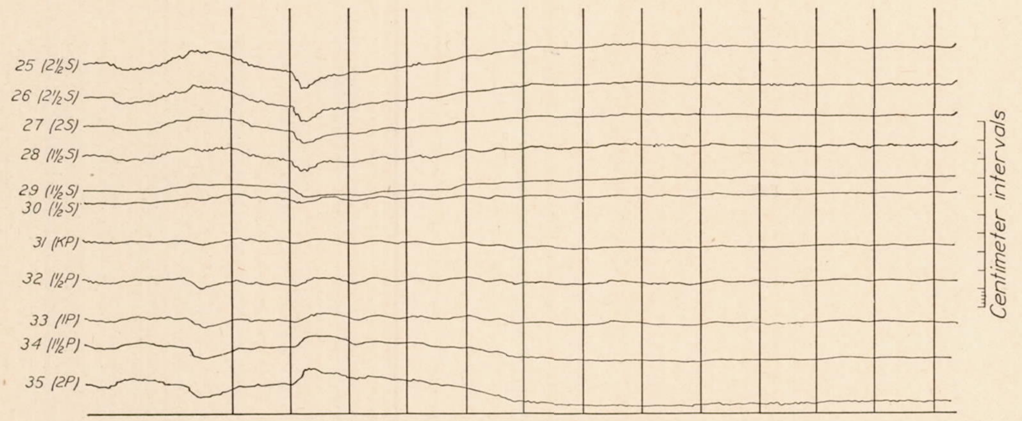


FIGURE 10.—Camera No. 1. Run No. 5

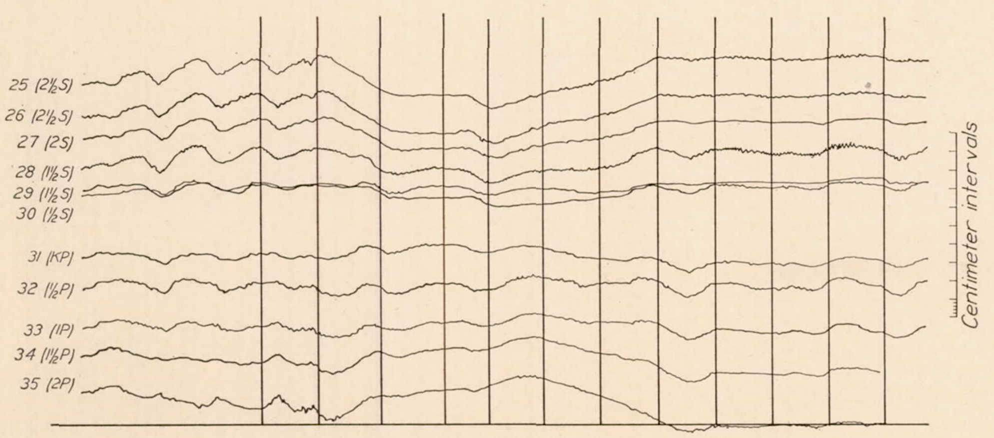


FIGURE 11.—Camera No. 1. Run No. 17

believed to be nearly coincident with run No. 4A. Some of the gages were not working satisfactorily at that time, and consequently, there are gaps in the record.

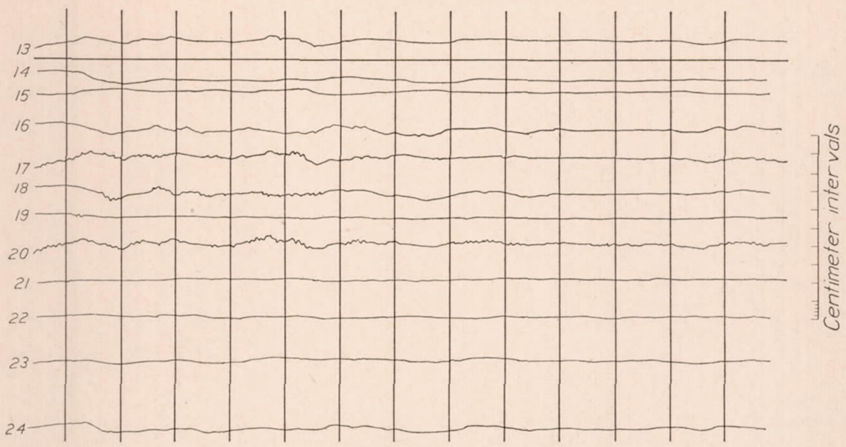


FIGURE 12.—Camera No. 1. Run No. 4

It is a curious fact that the most severe stresses were always recorded immediately after taking off from the mooring mast. A possible explanation is that during the first few minutes

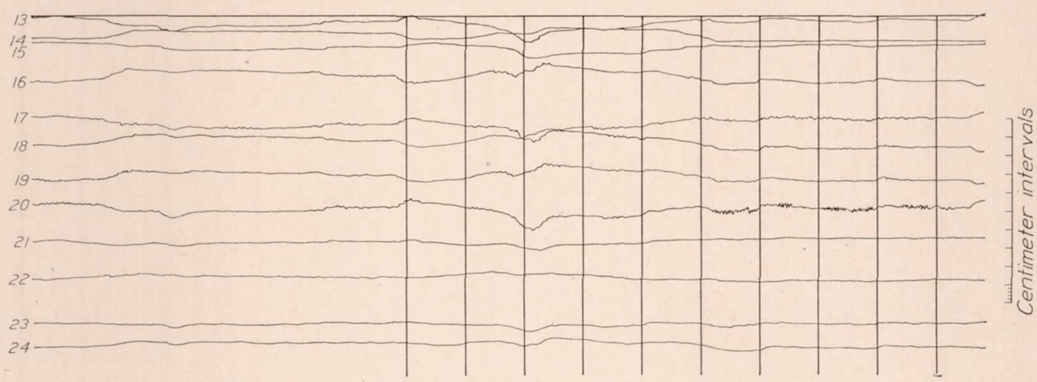


FIGURE 13.—Camera No. 2. Run No. 3

of flight, the airship lost superheat, causing a progressive change of trim that made the airship unsteady on the controls, with consequent rapid fluctuations in the bending moments.

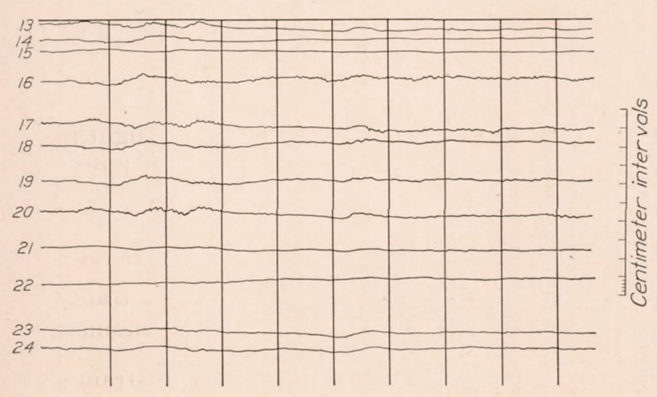


FIGURE 14.—Camera No. 2. Run No. 4

COEFFICIENTS OF AERODYNAMIC BENDING MOMENT

In order to understand the significance of the strains recorded by the strain gages, two steps are necessary—first, to convert the recorded strains into bending moments according to

the relation already derived; second, to express the bending moments in coefficient form for comparison with the tail surface forces and theoretically derived bending moment coefficients. A nondimensional coefficient is derived as follows:

For geometrically similar distributions of air pressure over airship hulls the resulting forces are proportional to the aerodynamic head $\rho\, v^2/2$, and to the surface area of the hull, or to the volume to the two-thirds power for similar shapes. The areodynamic bending moment

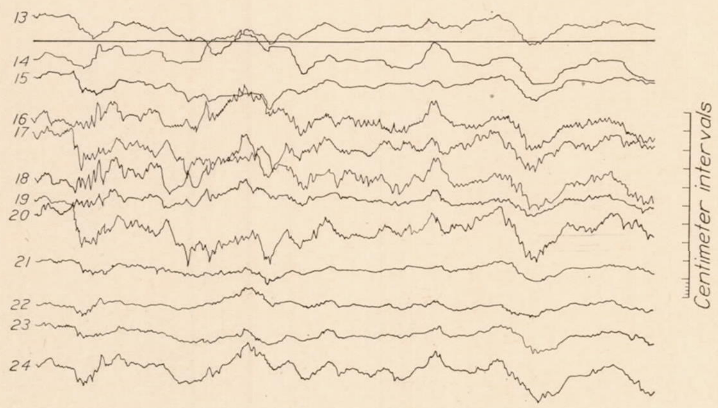


FIGURE 15.—Camera No. 2. Take-off from mast

is proportional to the total force and the length of the hull. Using these relations, the bending moment coefficient is defined by

$$C_M=\frac{M}{q\,V^{2/3}\,L}$$

where

C_M = the coefficient of aerodynamic bending moment.
M = the aerodynamic bending moment.
q = the aerodynamic head $\rho\, v^2/2$.
V = the air volume of the airship.
L = the over-all length of the airship.

For the *Los Angeles*, $V^{2/3}=20{,}000$ sq. ft., and $L=200$m. Therefore, if M is expressed in m lb., and q in lb./sq. ft.,

$$C_M=\frac{M}{4{,}000{,}000\, q}$$

Some values of C_M calculated from the observed values of q and the amplitudes of the strains are given in Table V. It is of great significance that flight in the rough air of the first day (run No. 4A) without maneuvers produced stresses corresponding to values of C_M approximately twice as great as were recorded in the maneuvers in the comparatively still air of the succeeding days of the trials.

CORRELATION OF BENDING MOMENTS AND TAIL SURFACE FORCES

Since the pressure distribution measurements showed the transverse forces on the hull to be small, it is to be inferred that the aerodynamic bending moments were mainly the result of tail surface forces opposed by the inertia of the hull against angular acceleration. This conclusion is confirmed by the insignificant strains shown by the strain gage records when the airship had settled to the condition of steady turning. It is unfortunate that satisfactory measurements of the angular accelerations could not be obtained. Lacking data on this subject, the best that can be done is to compare the relation between the observed values of the bending moment and tail surface force coefficients with their theoretical relation when the tail surface force is opposed only by angular acceleration.

In Part I of this report, the tail surface force coefficient C_{NF} is defined by

$$C_{NF}=\frac{2F}{S\,\rho\,v^2}=\frac{F}{Sq}$$

where

F = the total force on the tail surface.
S = the total area of the vertical or horizontal tail surface = 2,540 sq. ft.
q = the aerodynamic head.

It may be shown that when a force on the tail surfaces is opposed only by angular acceleration of the airship, a bending moment of about 31 m lb. is produced at frame 70 for every 1-pound force on the surfaces. It follows that in that condition

$$\frac{C_{NF}}{C_M}=\frac{F}{Sq}\times\frac{V^{2/3}\,L\,q}{M}=\frac{V^{2/3}\,L}{31\,S}=50.8$$

It may be seen from Table V that the ratio C_{NF}/C_M varied from 20 to 64, indicating that although the transverse forces were small and irregular, as indicated by the pressure measure-

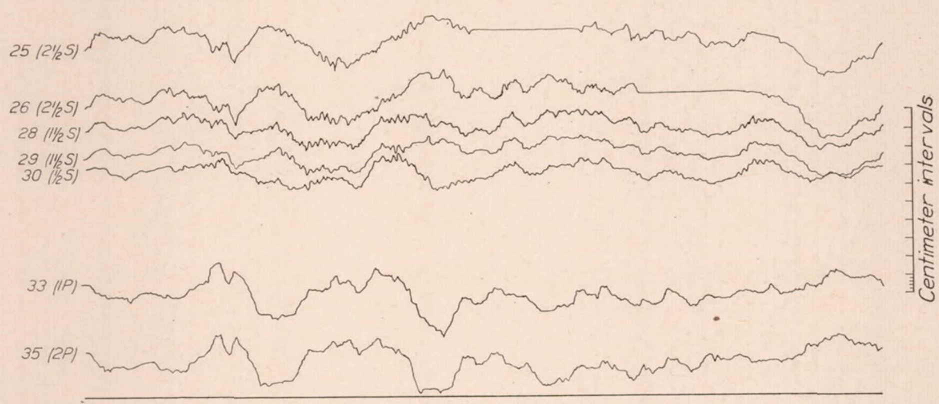


FIGURE 16.—Camera No. 1

ments, their resultant was sufficient to have a very considerable effect on the bending moments, sometimes adding to and at other times subtracting from the effect of the tail surface force. In the rough air run, No. 4A, C_{NF}/C_M is only 27, showing that in rough air the forces on the hull are of relatively greater importance than in most still air maneuvers.

APPLICATION TO DESIGN

In comparing the comparatively moderate forces recorded in still air maneuvers with the much greater forces in rough air flight, it should be borne in mind that the trials were made at rather moderate speed. It is to be expected that in still air maneuvers with any given helm angles, the aerodynamic forces will vary as the square of the speed, and the coefficients C_{NF} and C_M will be constant. On the other hand, when flying in rough air, the angles of attack resulting from sudden changes in the wind velocity will diminish with increasing speed of the airship. Consequently, the forces in rough air vary more nearly as the ship's speed, and the coefficients inversely as the speed.

The high value of 0.0128 calculated for C_M in run No. 4A occurred at only 50 knots speed. Assuming C_M for rough air to be inversely proportional to the speed, its magnitude at 64 knots in the same air conditions would have been only 0.01. It has been accepted practice to design rigid airships, including the *Los Angeles*, for a maximum aerodynamic C_M of about 0.01 at the airship's full speed, plus a material factor of safety of 2.0 to 2.5. The observations in the ex remely rough air of the first day of the flight trials indicated that the strength of the *Los Angeles* is sufficient for these conditions, but there is not much margin for hitting a violent and sharply defined wind squall at high speed.

The most recent practice in large airship design has tended toward provision of sufficient strength for a maximum C_M of about 0.02, which theoretical calculations show to be sufficient to withstand a sharply defined squall having a velocity of 60 ft./sec. transversely to the airship's longitudinal axis. This was the squall condition specified in the Navy Department's Airship Design Competition, 1928. It provides a large margin of strength beyond the most severe conditions encountered in the flight trials of the *Los Angeles*.

CONCLUSIONS

The largest aerodynamic forces and bending moments observed in the trials corresponded to coefficients astonishingly close to the design assumptions of the Zeppelin Company. The large airships of the future must be designed to encounter thunderstorm conditions which in the past have been regarded as avoidable hazards, and greater strength than that of the *Los Angeles* is therefore required.

Experiments should be continued to determine the angular and linear accelerations of airships in rough air. For such experiments there is great need to improve the sensitivity and reliability of the instruments at present available.

The risks attendant upon deliberately flying aircraft into thunder squalls are too great to be accepted, but every effort should be made to determine the structure of the air in squalls by means of wind-recording instruments mounted on lofty towers or by sensitive recording accelerometers carried in pilot balloons. Such researches would necessarily be expensive but of inestimable value to the science of air navigation.

Bureau of Aeronautics,
Navy Department,
December 3, 1928.

TABLE I

POSITIONS OF FORWARD GROUP OF STRAIN GAGES IN U. S. S. "LOS ANGELES," APRIL AND MAY, 1926

Gage No.	Position
1	Longitudinal ½S low base, forward of frame 115.
2	Longitudinal KS apex, forward of frame 115.
3	Longitudinal 1S low base, forward of frame 130.
4	Longitudinal 2S low base, forward of frame 145.
5	Longitudinal 1S low base, forward of frame 145.
6	Longitudinal 1S low base, forward of frame 160.
7	Longitudinal O apex, forward of frame 160.
8	Longitudinal 1P low base, forward of frame 145.
9	Longitudinal 2S low base, forward of frame 130.
10	Longitudinal 1P low base, forward of frame 130.
11	Longitudinal 2P low base, forward of frame 130.
12	Longitudinal KS apex, forward of frame 130.

Note.—Longitudinals are numbered 0, ½, 1, 1½, 2, etc., to 6 from the bottom to the top of the airship. S and P denote starboard and port sides, respectively. The longitudinals along the top of the keel are designated KS and KP. The terms low base, high base, and apex refer to the three channels or booms of the longitudinals.

TABLE II

POSITIONS OF REAR GROUP OF STRAIN GAGES IN U. S. S. "LOS ANGELES," APRIL AND MAY, 1926

Gage No.	Position
13	Longitudinal 1 S low base, forward of frame 40.
14	Longitudinal 1 P low base, forward of frame 40.
15	Longitudinal 1 S low base, forward of frame 55.
16	Longitudinal 1 P low base, forward of frame 55.
17	Longitudinal 1 S low base, forward of frame 85.
18	Longitudinal 1 P low base, forward of frame 85.
19	Longitudinal 1 P low base, forward of frame 70.
20	Longitudinal 1 S low base, forward of frame 70.
21	Longitudinal K S out base, forward of frame 40.
22	Longitudinal K P out base, forward of frame 40.
23	Longitudinal K S apex base, forward of frame 85.
24	Longitudinal K P apex base, forward of frame 85.
25	Longitudinal 2½S high base, forward of frame 70.
26	Longitudinal 2½S low base, forward of frame 70.
27	Longitudinal 2S low base, forward of frame 70.
28	Longitudinal 1½S low base, forward of frame 70.
29	Longitudinal 1½S high base, forward of frame 70.
30	Longitudinal ½S low base, forward of frame 70.
31	Longitudinal K P apex, forward of frame 70.
32	Longitudinal ½P low base, forward of frame 70.
33	Longitudinal 1 P low base, forward of frame 70.
34	Longitudinal 1½P low base, forward of frame 70.
35	Longitudinal 2P low base, forward of frame 70.

(See note to Table I.)

TABLE III

RECORD OF TESTS ON U. S. S. "LOS ANGELES," APRIL AND MAY, 1926

Date	Run No.	Maneuver
Apr. 27	1	Rough air flying on course.
	2	Do.
	3	Do.
	4	Do.
	5	Do.
	6	Do.
	7	Do.
	8	Do.
	9	Do.
	10	Do.
Apr. 30	1	Turn with 12° R. rudder at 1,050 R. P. M.
	2	Do.
	3	Turn with 8° R. rudder at 1,050 R. P. M.
	4	Turn with 12° L. rudder at 1,050 R. P. M.
	5	Turn with 8° R. rudder at 1,230 R. P. M.
	6	Turn with 12° R. rudder at 1,230 R. P. M.
	7	Running through squall.
	8	Do.
May 7	1	Reversal, 8° R. and L. rudder at 1,050 R. P. M.
	2	Do.
	3	Reversal, 12° R. and L. rudder at 1,050 R. P. M.
	4	Turn, 8° R. rudder at 1,050 R. P. M.
	5	Turn, 8° R. rudder at 1,230 R. P. M.
	6	Turn, 12° R. rudder at 1,230 R. P. M.
May 13	1	Rough air after leaving mast.
	2	Turn, 12° R. rudder at 1,230 R. P. M.
	3	Turn, 8° L. rudder at 1,050 R. P. M.
	4	Turn, 12° R. rudder at 1,050 R. P. M.
	5	Reversal, 8° R. and L. rudder at 1,050 R. P. M.
	6	Reversal, 12° R. and L. rudder at 1,050 R. P. M.
	7	Missed.
	8–12	Deceleration tests.
	13	Turn, 12° R. rudder at 1,050 R. P. M.
	14	Reversal, 12° R. and L. rudder at 1,050 R. P. M.
	15, 16	Deceleration tests.
	17	Reversal, 12° R. and L. rudder at 1,230 R. P. M.

TABLE IV

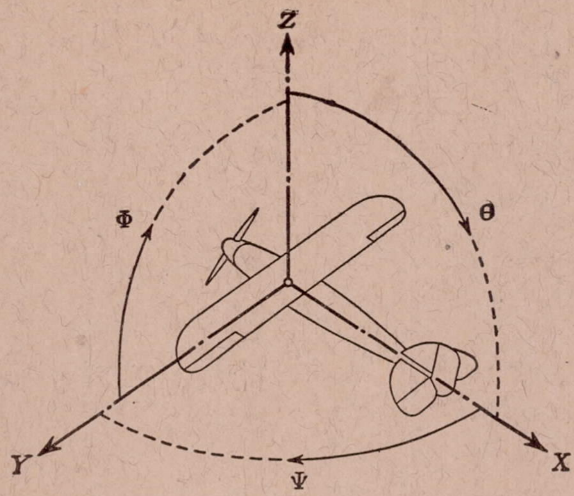
U. S. S. "LOS ANGELES" TESTS—TABLE OF DATA (AS TAKEN FROM AIRSHIP'S LOG AND AEROLOGICAL STATION)

Date	Run No.	Time of starting (eastern standard)	Air temperature	Altitude	Corrected sea level barometer
Apr. 27	1	11:38:23	42	1,630	30.092
	2	12:56:23	42	1,800	30.076
	3	13:16:58	42	1,800	----------
	4	13:34:50	42	1,800	----------
	5	13:53:54	42	1,800	30.04
	6	14:17:42	42	2,200	----------
	7	14:29:16	42	2,500	----------
	8	14:43:02	----------	2,500	----------
	9	14:55:28	41	2,500	30.03
	10	15:06:00	41	2,500	----------
Apr. 30	1	11:39:50	51	2,700	----------
	2	12:01:35	51	2,700	29.896
	3	13:00:24	58	1,500	29.885
	4	13:10:57	----------	1,530	----------
	5	13:20:25	58	1,500	----------
	6	14:12:51	----------	1,400	29.87
	7	14:42:33	58	2,000	----------
	8	14:53:13	57	2,000	29.86
May 7	1	17:28:33	63	2,500	29.83
	2	17:43:03	----------	2,500	----------
	3	18:03:12	62	2,500	29.82
	4	18:21:44	61	3,000	----------
	5	18:45:27	----------	----------	----------
	----------	Stopped.	----------	----------	----------
	6	19:10:15	61	2,500	29.83
May 13	1	10:32:54	57	2,500	29.78
	2	10:46:25	----------	----------	----------
	3	10:56:11	57	2,500	----------
	4	10:06:03	----------	2,500	29.78
	5	11:15:25	----------	2,500	----------
	6	11:41:36	59	2,100	29.76
	7	----------	----------	----------	----------
	8	14:00:40	60	2,500	29.73
	9	14:08:24	----------	2,500	----------
	10	14:22:32	61	2,500	----------
	11	14:33:14	----------	2,500	----------
	12	14:40:20	61	2,500	29.70
	13	16:38:40	61	2,900	29.70
	14	16:57:22	60	2,900	29.71
	15	17:19:37	60	2,900	----------
	16	17:30:43	61	2,900	----------
	17	17:47:20	----------	2,900	29.72

TABLE V

TAIL SURFACE FORCE AND HULL BENDING MOMENT COEFFICIENTS

Run maneuver	Rudder position	q lb./sq. ft.	F lb.	M m lb.	C_{NF}	C_M	$\frac{C_{NF}}{C_M}$
	Lower fin and rudder						
4B (turn)	9.70° L.	6.19	1,168	74,000	0.149	0.0030	50
4C (turn)	8.30° R.	4.37	1,300	64,000	.235	.0037	64
5C (turn)	7.85° R.	5.93	1,304	112,000	.173	.0047	37
2B (turn)	12.75° R.	4.47	756	118,000	.133	.0066	20
13D (turn)	12.95° R.	3.95	984	94,000	.196	.0059	33
5D (reversal)	4.50° L.	5.62	1,679	105,000	.236	.0047	50
3C (reversal)	6.50° L.	5.36	1,817	143,000	.268	.0067	40
17D (reversal)	12.50° R.	7.96	1,922	144,000	.190	.0045	42
	Starboard fin and elevator						
4A (rough air)	----------	8.01	3,501	410,000	0.349	0.0128	27



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS} \quad C_M=\frac{M}{qcS} \quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $=T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.